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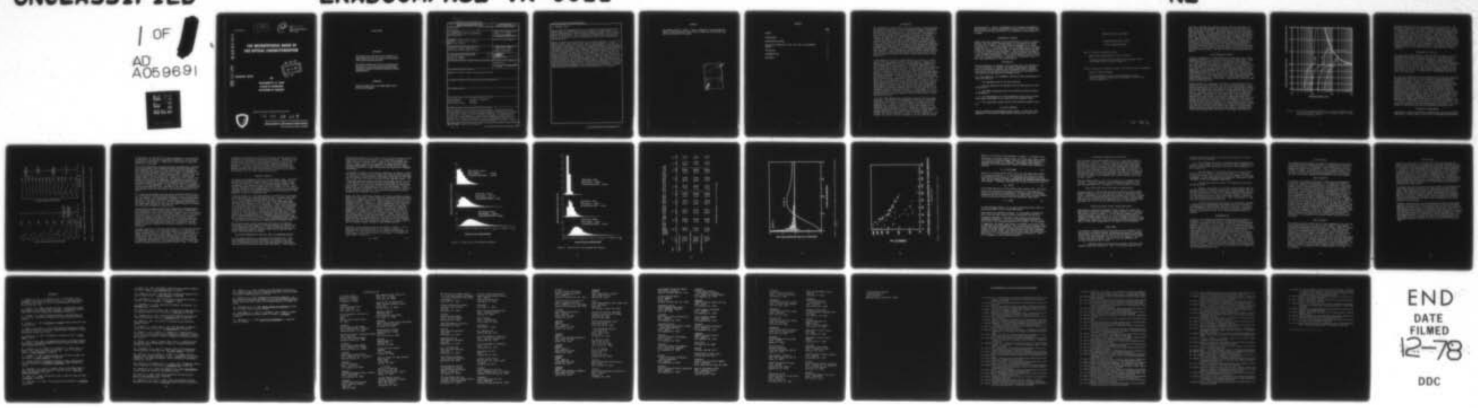

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THE MICROPHYSICAL BASIS OF FOG OPTICAL CHARACTERIZATION

AUGUST 1978

By

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The increasing use by the Army of the various types of electro-optical (EO) devices necessitates a test and evaluation program to determine the performance of these devices under a variety of weather conditions - the foggy condition, in particular. The presence of fogs seriously degrades the effectiveness of visible and infrared sensors, no matter how well-designed and engineered the sensors are. It would be impractical as well as uneconomical to test and evaluate each device individually under different atmospheric conditions. A more

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20. ABSTRACT (cont)

logical and direct approach would be to characterize and develop physical and optical models of fogs through extensive microphysical, meteorological, and spectral measurements at selected spectral regions, locations, and at different periods of fog evolution. Thus, microphysical characterization may aptly be said to be the basis of optical characterization under various meteorological foggy conditions.

However, microphysical characterization is not without problems of its own. This report presents a brief review of the state of fog microphysics. Careful inspection of fog spectra from numerous journal papers appears to indicate that on the average a large number of fogs and, to some extent, clouds may be adequately represented by six distribution histograms of varying spectral widths. By forcing these distributions to contain the same liquid water content of 0.10 g m^{-3} which is reasonable for most fogs, optical properties in the visible and 10.5-micrometer regions are examined as a function of liquid water, visibility, and volume extinction. While preliminary, this study seems to suggest that the fog liquid water content, being a derived quantity in all cases, may not be an efficient parameter to use in optical characterization. When the battlefield application of optical characterization is of primary consideration, it is all the more essential to establish the vital statistics of fog microphysical evolution through coordinated microphysical and micrometeorological measurements together with transmission observations at different strategic places of interest.

PREFACE

The authors thank Dr. James E. Jiusto, Atmospheric Sciences Research Center, State University of New York at Albany, for his critical comments and review of this report.

CONTENTS

INTRODUCTION

The increasing use by the Army of the various types of electro-optical (EO) devices necessitates a test and evaluation program to assess the performance of these devices under a variety of weather conditions - the most pressing problem being the foggy condition. The presence of fog seriously degrades the effectiveness of visible and infrared sensors, no matter how well designed and engineered the sensors are. It would be impractical as well as uneconomical to field test and evaluate each device individually under different atmospheric conditions. A more economical and logical approach would be to categorize and develop physical and optical models of fogs through well-conceived microphysical, meteorological and spectral measurements at selected spectral regions, locations, and at different stages of fog and dense haze evolution. Thus, microphysical characterization through modeling with selective verification measurements may aptly be said to be the basis of optical characterization under various meteorological foggy conditions.

If the objective of optical characterization is to serve as a rather general guide for research, design, and development, a computer program such as LOWTRAN 3B [1] may serve the purpose when amended to include appropriate fog optical models. While this remodeling is not easy in view of the complexities of fog microstructure, some generalized and workable models could be derived. In fact, Jiusto [2] has presented a conceptual structural model that specifies the average characteristics of radiation fog and of advection fog. More detailed models depicting fog variable changes with time are now being developed (see fog modeling section). By suitable adjustment, fogs of any intensities may be simulated with corresponding changes in visibility. On the other hand, if the objective is to develop models for testing and evaluating the performance of EO weapon systems with a particular battlefield location in mind and for possible use under varied battlefield environmental conditions, then such generalized models as derived by Jiusto would no longer be adequate, and the fog data published in the literature would no longer be sufficient. In other words, it is not possible at present to construct reasonable optical models for fog for the battlefield EO Systems Atmospheric Effects Library (SAEL) without additional data base.

It is the latter objective for battlefield location that this report addresses. The state of fog microphysics on the basis of materials drawn partly from Jiusto's [2,3] and Mason's [4] works will be discussed briefly. Efforts in numerical modeling for predicting fog formation and dissipation in terms of liquid water content will be mentioned, and investigation of fog microphysics in relation to fog optical properties will be presented. Preliminary findings appear to suggest that the fog liquid water content, especially when it is derived from droplet spectra as is true of the data inspected for this project, may not be a reliable parameter to be used alone in optical

characterization. Finally, recommendations for complete microphysical, meteorological, and optical measurements together with the criteria for site selection and data handling will be discussed, and conclusions will be drawn.

MICROPHYSICAL FACTORS

Without some prior knowledge of the characteristics of fogs, to proceed directly into fog optical characterization is like going to a tailor and asking him to make a suit with minimal measurements or by visual inspection only. If the body happens to be a standard one, the finished product may fit without further ado. Not unlike human bodies, the fogs do come in "different sizes and shapes." What one hopes to accomplish in EO SAEL optical characterization is not much different from that of a men's clothing manufacturer. With a limited number of sizes, he hopes to fit all the men in the world. Therefore, it is essential that we gain some understanding of fog characteristics.

Microphysics

Cloud microphysics, in contrast to an investigation of the characteristic forms, geneses, and dynamics of clouds in meteorology, involves study of the physical, chemical, and thermodynamic basis of droplets, ice crystals, and nucleation particles as well as the distribution of these particles which make up an individual cloud.

To a cloud physicist, the fundamental features of the microstructure of clouds and fogs are:

1. The aggregate state of the cloud particles.

2. The size spectra of the droplets, and the form and size of the ice particles.

3. The number concentration per unit volume and related statistical parameters.

4. The concentrations of cloud condensation nuclei and ice nuclei that promote development of the liquid and solid hydrosol phase.

5. The liquid water content and the total moisture content of the air.

The Local Character

Fogs are essentially ground-based stratus clouds. As such, the local dependence of fog physical characteristics has been well known for a

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THE MICROPHYSICAL BASIS OF FOG

OPTICAL CHARACTERIZATION

Page 9, third full paragraph on page

Change lines two and three to read as follows:

"since the beginning of this century (such as those cited in aufm Kampe's paper [16]) have sought a . . ."

Page 11, second full paragraph on page, 11th and 12th lines in paragraph

Change to read as follows:

"one correspondence at these two wavelengths. Had the authors of previous reports had some perception of the nature of fog microphysics, . . ."

long time. Although not completely divorced from the prevailing synoptic situation, the formation and dissipation of fogs are highly influenced by local conditions - especially the local terrain and boundary layer environment. Fog forecasting often demands that the forecaster work out a forecast technique specifically for each fog at each station. Generally, fogs may be separated into two types: radiation and advection. Their microphysical characteristics would be different, and fogs at two different places, even though classified as of the same type (radiation or advection), may have entirely different microstructures. For instance, the microstructure of the radiation fogs observed at Travis Air Force Base [5] at the western edge of the San Joaquin Valley, California, is quite different from that taken at the Skelly Field [6] near Fort Rucker, Alabama. The former place is more polluted than the latter.

Cloud Condensation Nuclei

The basic ingredients of a cloud droplet are liquid water (or ice) and condensation nuclei (or ice nuclei in the case of an ice cloud). These nuclei generally belong in the family of large and giant particles; i.e., their diameters are equal to or greater than 0.1 micrometer and are nearly always at least partially hygroscopic. For a nucleus to grow into a droplet, the air must have attained a certain degree of supersaturation. At low supersaturations, only those nuclei which are large enough and hygroscopic enough will ever go across the hump of the so-called Köhler curve (Fig. 1). Once over the hump (i.e., the so-called critical size or critical supersaturation), these nuclei formally become cloud droplets and can in theory grow to any size, provided a small amount of supersaturation is maintained. Those failing to make the hump are called haze particles.

A NaCl nucleus of 0.1 micrometer in radius has a mass of about 10^{-14} g. The mass of the liquid water of a haze particle may be about the same order of magnitude as its nucleus mass or at most three orders of magnitude greater, depending on the degree of ambient supersaturation in the air [7]. The mass of the liquid water of a droplet is at least three orders of magnitude greater and may exceed eight orders of magnitude for raindrops. While there is little doubt that a fog droplet can be regarded as a water droplet, there could be appreciable doubt about taking a haze particle as a water droplet, especially at very low supersaturations such as may often exist in a fog. However, it should be pointed out here that the existence of a large number of haze particles in a fog, while seriously attenuating the visible transmission, contributes little to the total water content; for example, a 10-micrometer droplet contains a thousand times more water than a 1-micrometer droplet and ten thousand times more than a 0.1-micrometer haze particle.

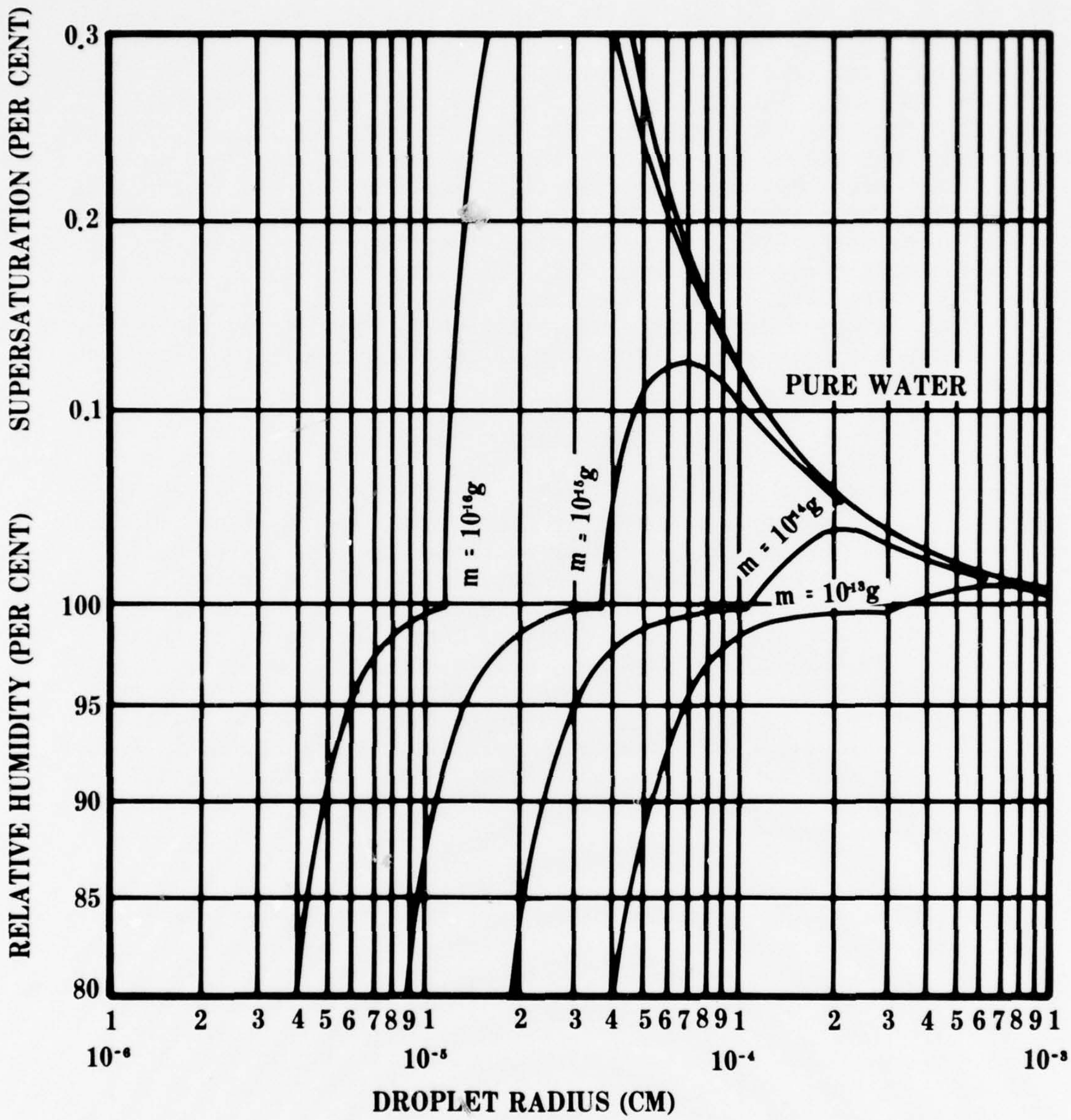


Figure 1. The equilibrium supersaturation as a function of droplet radius for solution droplets containing the indicated masses of sodium chloride (from Mason, 1971).

No fog or haze would exist in an atmosphere free of any nuclei. The presence of these nuclei in different number concentrations at different places would have a definitive influence on the fog microstructures at these places. Here, the local environment becomes an important factor in both formation and microstructure. Given the same degree of supersaturation, the fogs in polluted areas tend to be thick and their size spectra narrower since more condensation nuclei would compete for the available moisture in the air, whereas the fogs over rural areas or the oceans, presumably much cleaner, tend to be moderate and their size spectra somewhat broader. Such inferences can be easily drawn from the studies by Jiusto [2,3], Mack and Pilié [5], and Low [6] in which the concentrations of cloud condensation nuclei were observed at regular intervals.

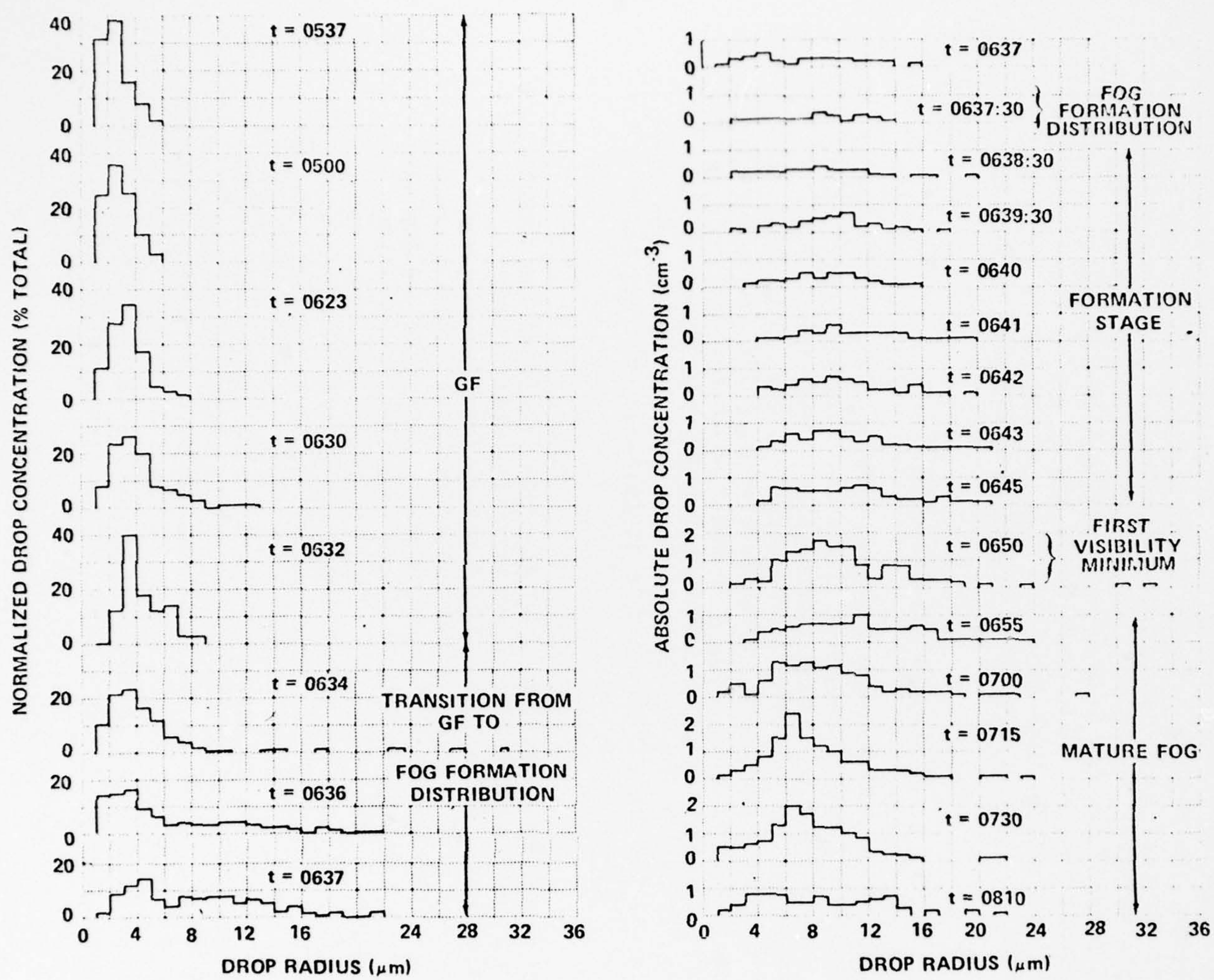
Microphysical Evolution

Like any other weather element, a fog goes through different stages of development from formation through dissipation. The same fog at the same place will exhibit different microphysical properties during different phases of its evolution. The mere fact that throughout the duration of droplet growth such microprocesses as collision, coalescence, and sedimentation go on continuously in addition to the usual micrometeorological fluctuations, the constant turbulent exchanges of heat and moisture inside the fog itself as well as between the fog and the ground below and the dry air above make it self-evident that the fog has a life of its own.

Not until quite recently has the cloud physicist realized the importance of examining a fog's entire life microphysically when attempting to categorize the fogs. Pilié et al. [8] first noticed the distinct changes with time size spectra, liquid water contents, droplet concentrations, and visibility as the fogs in the Chenmung River Valley near Elmira, New York, evolved from mere ground fogs through formation, maturity, and dissipation (Fig. 2). They estimated that about one quarter of a fog's life used in formation, two quarters in maturity, and one quarter in dissipation. Low's analysis [6] of the fogs at the Skelly Field near Fort Rucker, Alabama, and those at the Redwood Valley near Arcata, California, appears to support their observations. More recently, in Goodman's investigation [9] of the advection fogs at a mountain top in the center of the San Francisco area in California, the life cycles of those fogs did not appear to be as well-organized. This is not too surprising since the mean windspeed varied from 3 to 10 m s^{-1}, reaching a maximum when fogs were advected over the sampling site.

Microphysical Measurements

Examination of some 50 fog drop-size distributions from the open literature cited in various places in this report is admittedly not extensive



NOTE: Data obtained at 0637 are presented in normalized and absolute form for comparison.

Figure 2. Drop size distributions obtained on 2 September 1970 (from Pilié et al., 1975).

or exhaustive. If the quality of these measurements is any indication of the type of fog data to be expected and adopted for optical characterization in the EO SAEL, it seems that no more effort is needed to garner more of the same.

Most of the researchers collected these data with mechanical impactors of various designs, while following somewhat different techniques in data reduction (see [4] and [10] for cloud physics instrumentation). Five researchers (Houghton and Radford [11], Webb [12], Eldridge [13], May [14], and Kunkel [15]) seemed interested more in testing their new droplet sampling devices than in fog properties or meteorological factors giving rise to fog formation. Pilié et al. [8], Low [6], and Goodman [9] explored such properties; fog microphysical evolution in each case was described in some detail together with supporting meteorological observations leading to fog formation either in the paper itself or in cited references. A number of the other investigators did not give their sampling sites. Most seem to be trying to characterize fogs through either the calculated or the observed parameter of visibility.

It is entirely conceivable that fogs having the same visibility value of 1 km may possess different microstructures, as will be discussed in the next section. The microphysical parameter of liquid water content was used in some cases in an effort to establish its relationship to visibility. Yet only Pilié et al. [8] made independent measurements of the liquid water contents of their fogs at regular intervals in conjunction with other microphysical observations.

Fog visibility has been so elusive that generations of meteorologists at the beginning of this century (such as those cited in aufm Kampe's paper [16]) sought a definitive relationship between liquid water content and visibility. Still, such a relationship defies clear-cut resolution. It may be obvious by now that while fog visibility may be used as a convenient parameter to grade fog intensity, it does not necessarily follow that the visibility value can be readily translated into some designation of fog microstructure under all circumstances, thereby making it possible to deduce its transmission property at some other wavelength.

Eldridge's analysis [17] of Arnulf and Bricard's [18] haze and fog data may offer some insight into a possible approach to the problems of optical characterization in the EO SAEL. The latter observed that the shapes of the distribution curves changed little in their so-called "nonevolving" fogs. Seizing upon such observation, Eldridge derived an expression relating visibility to liquid water content. However, he noted that the constants in his expression would be different when applied to dense haze and the so-called "selective" fogs. This seems

to suggest that one type of fog at one particular site may obey such an exponential law having a particular set of constants. Furthermore, this may imply that the shapes of the distribution curves of one fog type at a place remain within narrow bounds despite spectral broadening or narrowing. If more or less true, this may explain why Houghton and Radford [11] were able to draw a beautiful straight-line relationship between visibility and liquid water content on a log-log scale, and so was Eldridge [19]; yet their lines do not coincide.

Numerical Modeling

The state of fog modeling is still at an experimental stage. The effort has been mainly directed toward formulating a general scheme for predicting fog evolution in terms of liquid water content without regard to dynamics, size spectra, or terrain and environmental effects. The physical foundation for fog modeling was laid by Rodhe [20] in a classical paper delineating the thermodynamics of the saturated and unsaturated processes as well as the turbulent transfer of heat and moisture in the formation of mixing (or advection) fog.

Fisher and Caplan [21] first demonstrated the feasibility of simulating the formation and dissipation of advection fogs. Following them, Mack et al. [22] developed a two-dimensional numerical model. In a continuing effort, Rogers and Eadie [23] made further improvement upon this model and subjected it to field tests. In modeling the radiation fogs, Zdunkowski and Nielson [24] formulated a rather complicated model in which the transport of long-wave radiation leading to fog formation was handled in great detail. Simplifying this approach to radiative transfer calculations while retaining the essential physical processes, Pilié et al. [25] developed a one-dimensional prediction model. Incorporating the desirable features of Zdunkowski and Nielson's model as well as those of Pilié's, Lala et al. [26] formulated a model of their own to test the sensitivity of the various micrometeorological variables in the prediction of occurrence or nonoccurrence of radiation fogs.

The above discussion briefly summarizes the state of fog modeling. These models are rather general in character and may be a valuable aid to fog forecasting and modification. Unless further developed to include droplet-size spectral evolution, they would not be too useful in optical characterization at present.

FOG OPTICAL PROPERTIES IN THE 0.55- AND 10.5-MICROMETER REGIONS

In cloud physics books (e.g., Borovikov [27] and Mason [4]), it has been suggested that cloud and fog droplet size spectra can be adequately represented by one or both of the two statistical functions: the lognormal distribution and the gamma distribution. Other proposed

distribution functions such as Best's [28] and Khrgian and Mazin's [29] have not received as wide attention, the former being somewhat too complicated to use and the latter a special case of the gamma distribution. Careful inspection of the shapes of approximately 50 fog drop-size measurements on hand appears to show that some fog samples are better fitted with a gamma distribution and others with a lognormal distribution.

To elucidate in general the fog optical properties and examine in detail the effects of different spectral shapes and widths on such properties, six distribution curves have been constructed, three each for the gamma and the lognormal distributions having different spectral widths. The liquid water content has been restricted to the same value of 0.1 g m^{-3} in the hope that this analysis may offer some guidance to the efforts in the optical characterization program of the EO SAEL and may provide some insight in the requirements of the field measurements. Figure 3 depicts the three histograms based on the gamma distribution, and Fig. 4 on the lognormal distribution. The relevant statistical and optical parameters are summarized in Table 1.

Before the table is discussed, however, two figures prepared by Stewart [30] will be inspected. Figure 5 shows the variations of the efficiency factors for extinction with water droplet radii in the 0.55- and 10.5-micrometer regions. Figure 6 is a scatter diagram of visibility versus attenuation at 10.5 micrometers. Having computed the total volume extinction coefficients of approximately 60 fog spectra at these two wavelengths, Stewart tried to correlate visibility with infrared attenuation. The correlation is not exactly encouraging, contrary to Roberts' [31] findings in his Grafenwöhr fog data. The point to be noted here is that there does not, in general, appear to be a one-to-one correspondence at these two wavelengths. Had the authors of the present report had some perception of the nature of fog microphysics, they would have recognized immediately that such one-to-one correspondence, provided that the fog data are creditable, is at best a special case for reasons already discussed in the preceding section.

Attention is now directed to some of the symbols in Table 1. It has been realized since the beginning of the century, according to Middleton [32], that there should be an inverse relation between the visual range in a fog and the mass of liquid water. aufm Kampe [16] gave Trabert's formula as

$$V_t = 2CR/W \qquad (1)$$

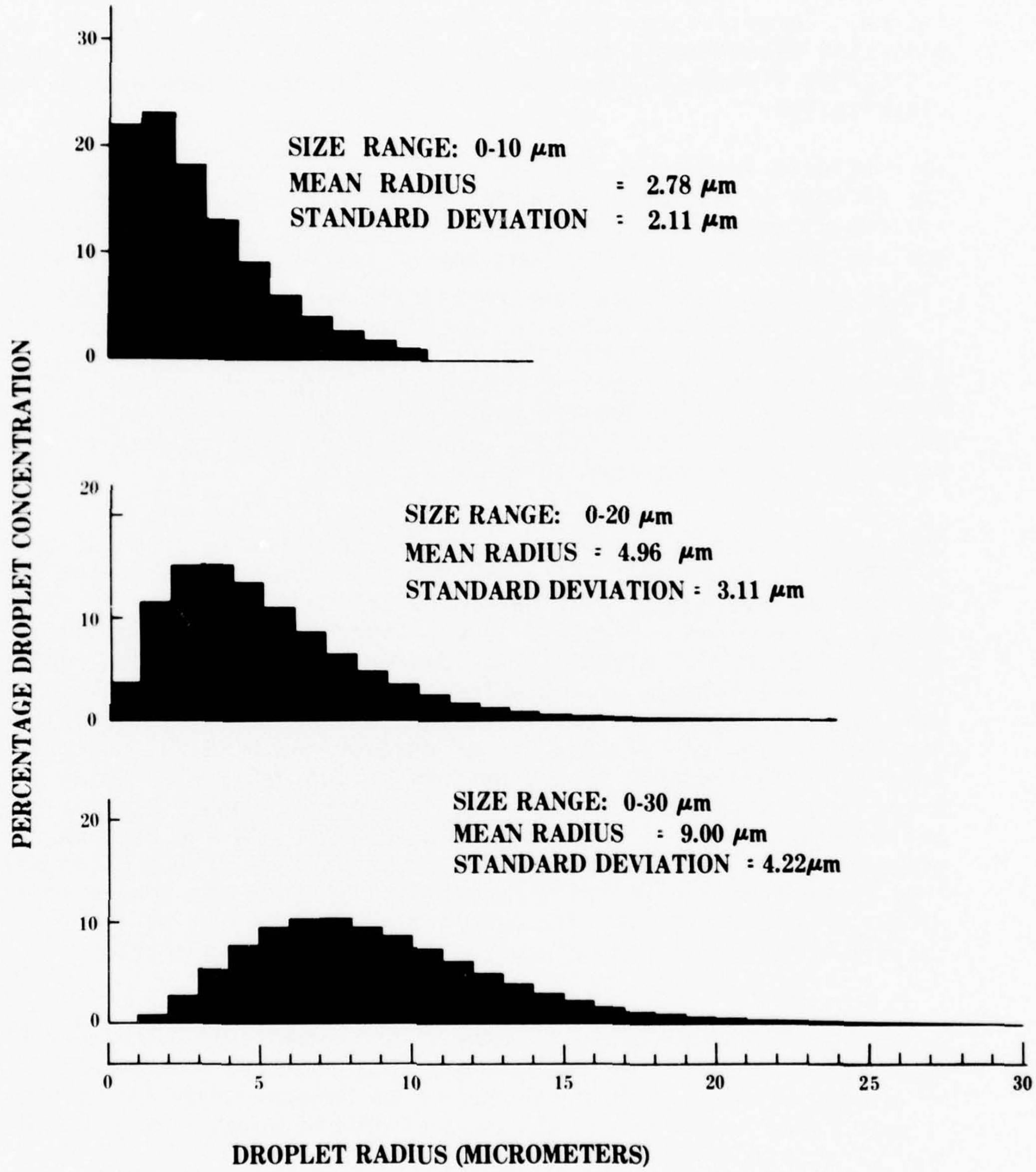


Figure 3. Three cases of the gamma distribution.

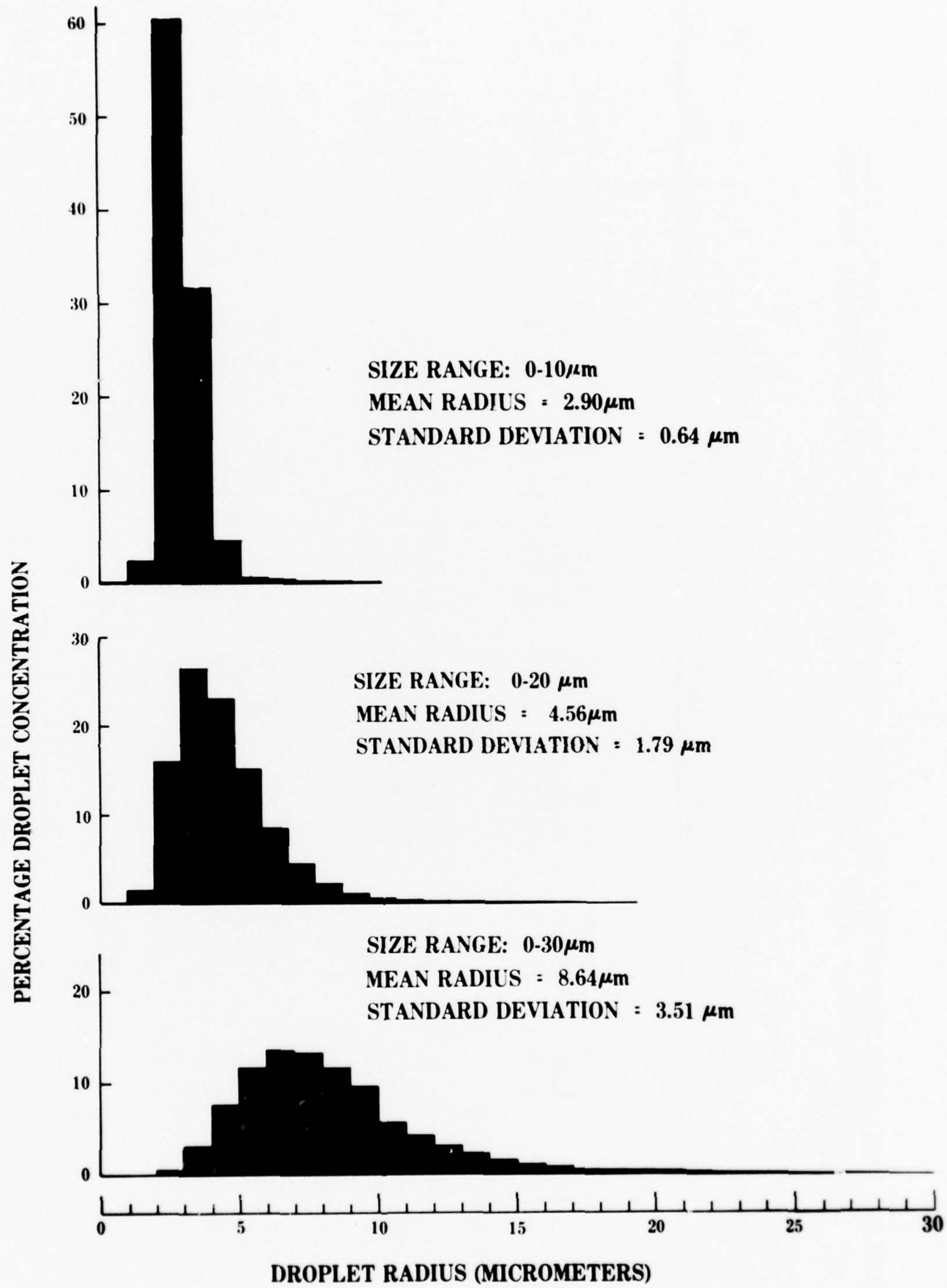


Figure 4. Three cases of the lognormal distribution.

TABLE 1. RELEVANT STATISTICAL AND OPTICAL PARAMETERS IN THREE DIFFERENT DROPLET SIZE DISTRIBUTIONS: GAMMA, LOGNORMAL, AND NORMAL, EACH HAVING DIFFERENT SPECTRAL WIDTHS.

Type	N (cc^{-1})	R_s (μm)	R_v (μm)	β_{ir} (km^{-1})	β (km^{-1})	V (km)	R_e (μm)	β^* (km^{-1})	V_t (km)	$\Delta\beta$ (%)	ΔV (%)
Gamma Distribution											
	351.50	3.49	4.08	15.24	28.31	0.136	5.58	68.77	0.145	138.7	6.6
	79.36	5.86	6.69	14.58	17.96	0.218	8.72	37.92	0.227	111.1	4.1
	18.74	9.94	10.85	12.84	11.97	0.327	12.93	19.69	0.337	64.5	3.1
Lognormal Distribution											
	841.40	2.97	3.05	12.97	51.71	0.076	3.22	54.81	0.084	6.0	10.1
	164.04	4.90	5.26	15.16	26.33	0.149	6.06	37.85	0.158	43.8	6.0
	23.52	9.33	10.06	13.53	13.31	0.294	11.70	20.21	0.305	51.8	3.7
Normal Distribution											
	161.30	5.15	5.29	15.36	28.63	0.137	5.58	31.56	0.146	10.2	6.6
	20.10	10.31	10.59	14.73	13.92	0.281	11.12	15.62	0.291	12.2	3.6
	5.97	15.46	15.88	11.37	9.04	0.433	16.75	10.52	0.437	16.4	1.0

Liquid Water Content = 0.1 g m^{-3} in all cases.

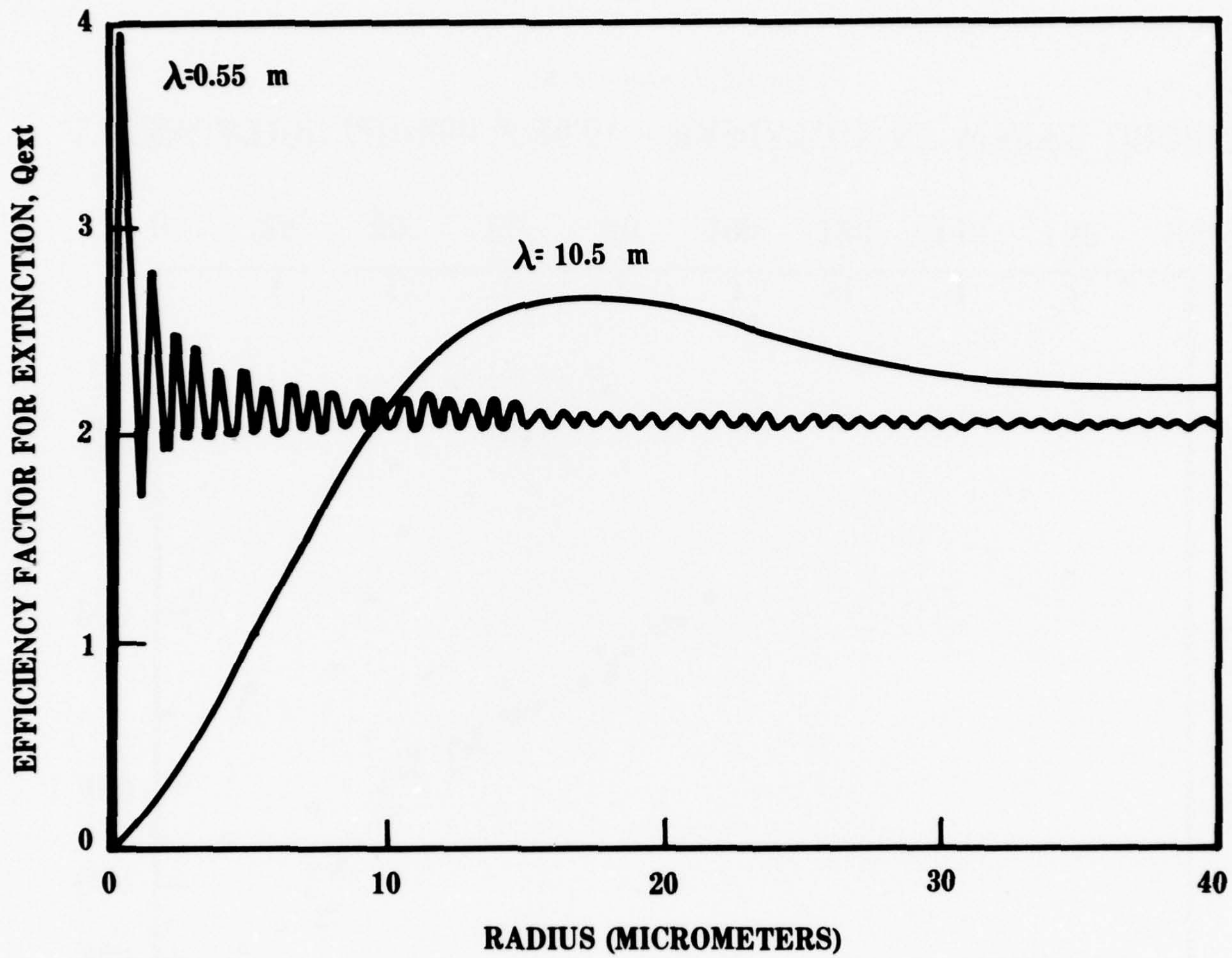


Figure 5. Efficiency factor versus droplet radius at 0.55μm and 10.5μm (from Stewart, 1977).

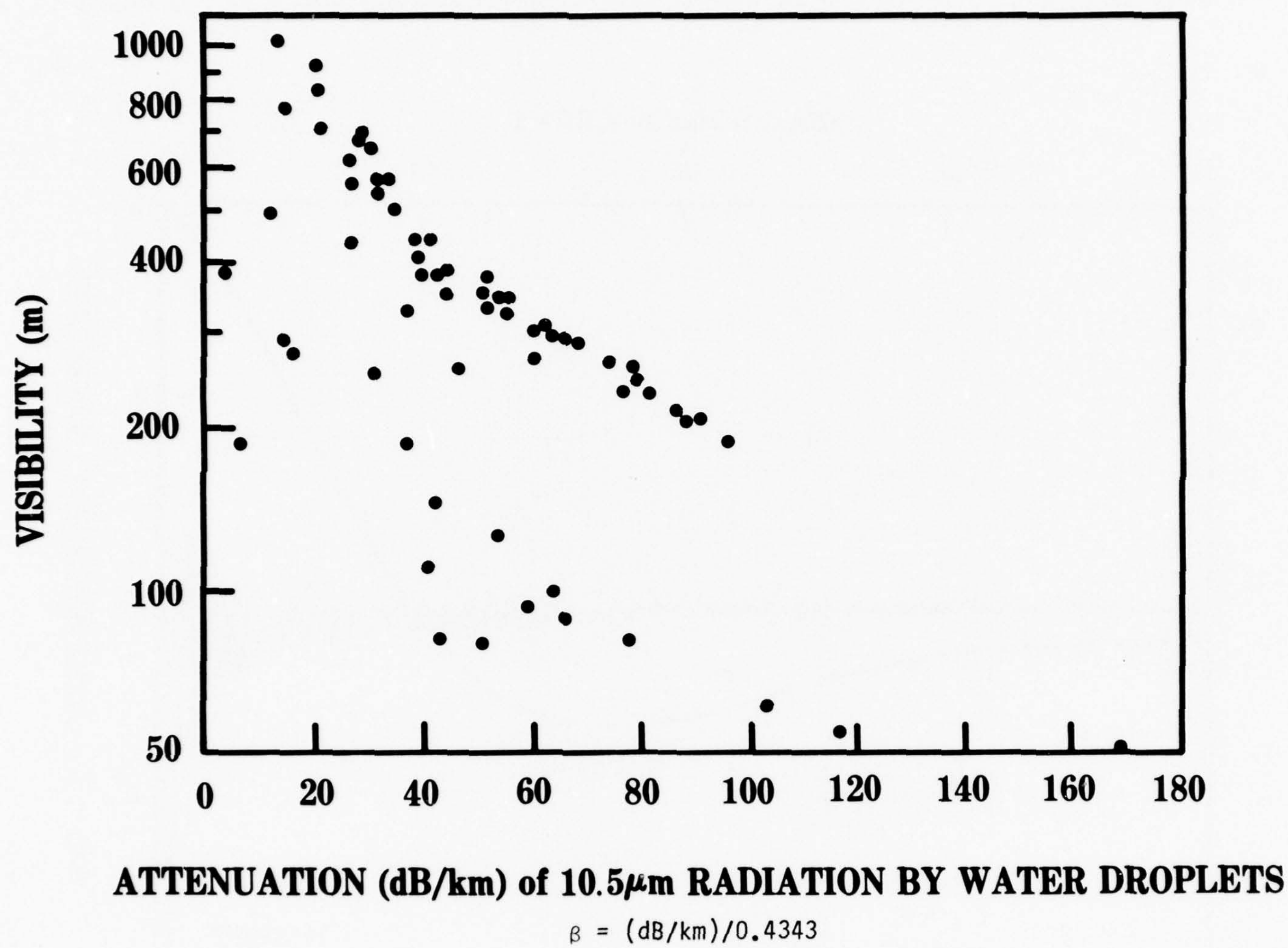


Figure 6. Visibility versus attenuation at 10.5μm (from Stewart, 1977).

where V_t is the visual range according to Trabert, C a constant to be determined, R some mean droplet radius, and W the liquid water content. It is not clear from aufm Kampe's text as to what central measure of a distribution function R is referred. Nevertheless, aufm Kampe and Weickmann [33] later showed that Trabert's formula should properly be given by

$$V_t = 2.608\ R_v^3/WR_s^2 \qquad (2)$$

where R_v is the mean-volume radius and R_s the root-mean-square radius. In the above expression, it is understood that the efficiency factor for extinction is set equal to 2. aufm Kampe and Weickmann concluded that, for the equation to hold, knowledge of the complete droplet spectrum was necessary. Thereupon, McCartney [34] defined an effective radius as

$$R_e = R_v^3/R_s^2 \qquad (3)$$

and asserted that the use of R_e enables one to handle, for a relatively narrow size distribution, scattering problems of a polydispersion in terms of an equivalent monodispersion. In other words, the following expression for the total volume extinction coefficient for water spheres in the visible should then be valid for relatively large drops:

$$\beta^* = 2N\pi R_e^2 \qquad (4)$$

β^* (for efficiency factor = 2) is used in distinction from β which is calculated exactly for the visible wavelength.

Other symbols are defined as follows: N is the number concentration per cc, β_{ir} the total volume extinction coefficient for the 10.5-micrometer wavelength, V the visual range given by the well-known Koschmieder formula ($V = 3.912/\beta$), $\Delta\beta$ the percentage deviation of β^* from β, and ΔV the percentage deviation of V_t from V. For the purpose of comparison, the normal distribution is included in the table, which is separated into three portions. The left-most portion contains, among others, the optical parameters which have been calculated strictly according to the Mie theory. The middle portion gives these parameters according to Eqs. (2)-(4) where the efficiency factor for extinction is taken to be 2. The right-most portion shows the deviations. Table 1 will be examined in the following categories:

Liquid Water Content Versus Visibility

Given the same liquid water content of 0.1 g m^{-3}, the visual range may vary from 76 m to 433 m, a factor of nearly six including the normal distribution, or to 327 m, a factor of greater than four excluding it. When the distribution is narrow, the visual range given by the gamma distribution is almost twice that given by the lognormal distribution, but it is almost the same as that given by the normal distribution. In contrast, when the spectral width is broad, the gamma and the lognormal distributions appear to produce comparable visual ranges, a difference of about 10 percent in our examples; their similarity may also be seen in Figs. 3 and 4.

With the Trabert formula in Eq. (2), an error up to 10 percent may be incurred. It appears, however, that the broader the spectrum is the less the percentage error, irrespective of the distribution function.

Exact Extinction Versus Extinction of Monodispersion

The table seems to indicate that the so-called effective radius recommended by McCartney [34] is not meaningful, even for the normal distribution. Nonetheless, note that when the lognormal distribution is narrow there is only a 6 percent deviation from true extinction. On the other hand, when the distribution is indeed narrow it is then doubtful whether one should use 2 at all for the efficiency factor in the visible.

Visible Extinction Versus Infrared Extinction

Some positive relationship apparently exists between the visible and the infrared extinction coefficients, however, bearing in mind Stewart's [30] scatter diagram in Figure 6. As the spectrum broadens, both coefficients decrease, except for the one in the lognormal distribution. Stewart's findings suggest that it is risky to proceed to relate visible extinction or visibility to infrared extinction without some prior knowledge, or some actual measurement, of the shape of the size spectra.

CONCLUSIONS

Six synthetic histograms depicting the gamma and the lognormal distributions having different spectral widths have been used to illustrate the problems involved in deriving and correlating the fog optical properties at the two wavelengths of 0.55 and 10.5 micrometers in relation to fog liquid water content. From the discussion presented, the following conclusions may be drawn:

1. Although coupled to the prevailing synoptic situations, fogs possess strong local characters. Even if of the same type, two fogs

at two different places may have different microstructures and hence different optical properties.

2. Data analyses may result in misleading and/or erroneous conclusions if one attempts to characterize or model fog microphysical and optical properties with observations limited to a small segment of a fog's entire life.

3. The same amount of liquid water found in a variety of fogs does not imply that they all have the same visibility. Therefore, liquid water content alone may not be a reliable measure of visibility in general. As yet, there exists no off-the-shelf liquid water content instrument to make an independent measurement.

4. The so-called effective radius for scattering calculations may not be useful.

5. However, there seems to exist some limited evidence that the same type of fog at a place may share similar microstructure; that is, the same distribution function with different spectral widths may hold for this particular fog. If so, it may then be possible to establish a certain empirical relation among liquid water content, visibility, and infrared attenuation for that place. Such a relationship is, however, not expected to hold universally.

6. Transmittance measurements through fog at the same time that microphysical and meteorological measurements are made are essential for development of optical models and their validation. This type of data is currently lacking and the correction of this data deficiency should be given high priority in any field measurement atmospheric program.

RECOMMENDATIONS

As noted in the introduction, generalized fog models are already in existence. By suitable adjustment of microphysical parameters, it is possible to simulate fogs of different intensities with corresponding changes in visibility. If the EO SAEL is to be designed for the purposes of testing and evaluating weapon systems in a particular battlefield location and/or for possible use under varied battlefield environmental conditions, then fog physical and optical models must be generated for that particular battlefield scenario since the generalized models will only supply misinformation. In the case of Germany (both East and West), which has a total area of about 182,000 square miles characterized by several climatic zones, it is quite conceivable that fog microstructures would differ in different zones. Fog microphysics in Stuttgart may not be the same as those in Hamburg or Berlin. In this section, a general outline will be presented as to where, what, and when to measure, and how to evaluate the mass of fog microphysical (and micrometeorological) data.

Site Selection

The climatic zones of Germany, as presently classified, may or may not be appropriate for fog characterization. An examination of fog climatology with reference to the present classification should indicate whether the present one is adequate. If not, a fresh effort in classification is needed. Otherwise, a place (and preferably another site far from cities) should be selected as representative of the zone on the basis of strategic importance and moderate or high fog incidence.

What to Measure

If the goal is to simply characterize or model the fog microphysical and optical properties for that place, it is perhaps sufficient to measure as a function of time droplet size distributions, liquid water content, aerosol and condensation nucleus concentrations, visibility, and infrared transmission in addition to the usual meteorological observations. For characterizing vertical inhomogeneity, a 300-m or higher steel tower is needed to provide a stable platform, and the same set of measurements taken simultaneously at suitably chosen levels. The present-day cloud physics instruments call for delicate handling even on the ground and hence a stable platform up in the air. However, if the goal is not only to model fog microphysics but also to infer the processes of fog formation and dissipation in the hope that some prediction scheme or model may be formulated for the place and used in the EO SAEL, more elaborate meteorological and micrometeorological observations are then required in addition to microphysical measurements so as to enable one to detect and sort out the parameters of particular importance, local or otherwise, which act in conjunction with the common physical processes to cause local fog formation and dissipation. In either case, it is imperative that current weather maps be consulted and noted.

When to Measure

This report has stressed that the very local dependence of fog calls for careful observation of a fog's entire life history; in other words, microphysical measurements should be made at frequent intervals from the beginning of fog formation through dissipation. Since most meteorological and micrometeorological instruments, including aerosol and condensation nucleus counters, can operate on their own without appreciable attention, they should be left on all the time at the site. Detailed soundings over the lowest 200 m above the ground surface should be taken prior to fog formation, during evolution, and after dissipation at regular intervals. Of utmost importance is the concurrent measurement of slant path transmission through fog at varying wavelengths. The spectral regions in such an endeavor should include the visible, 3-5 micrometers, 8-14 micrometers, and millimeter bands as a minimum if at all possible.

Data Handling

Depending on the number of sampling sites finally decided upon, the amount of meteorological and microphysical data would, nevertheless, be quite massive. While data processing may be tedious and time-consuming, it is relatively straightforward once a definite and logical procedure is worked out. The critical phase of data handling is the evaluation of these data, especially those on fog microphysics in view of the crude and unreliable state of cloud physics instrumentation. For droplet sampling, evidence must be available to show that the instrument has been accurately calibrated prior to its use and/or that it has produced fog data comparable to those of a different design. If the data on fog droplet spectra should be doubtful, all other supporting measurements would have lost their values.

The droplet data should be carefully cross-checked for consistency with liquid water content, visibility, and infrared transmission measurements. These measurements should lie well within 15 percent of one another for a sampling period no greater than perhaps 5-10 minutes, bearing in mind these instruments would have different time constants. Only in the manner as outlined above, may it be possible to properly delineate and characterize or model the fog microphysical and optical properties for one place.

Although a program such as the one presented here would be very costly, when the final total cost of the acquisition of an array of EO weapon systems for battlefield use is considered, the cost of a well-conceived fog characterization program in the battlefield EO SAEL, which is not only essential to the test and evaluation of these systems but may also find use under battlefield conditions, is rather insignificant. Current half-hearted efforts in battlefield fog/optical characterization will only produce fog data no better than what is already available in the literature--adequate for general use but not for battlefield application.

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